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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> <b>G06T 5/50</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 97/25690</b> <b>(43) International Publication Date:</b> 17 July 1997 (17.07.97)
<b>(21) International Application Number:</b> PCT/SE97/00017 <b>(22) International Filing Date:</b> 9 January 1997 (09.01.97) <b>(30) Priority Data:</b> 9600083-1 9 January 1996 (09.01.96) SE <b>(71)(72) Applicant and Inventor:</b> OLSSON, Kjell [SE/SE]; Säningsvägen 17, S-175 45 Järfälla (SE).		<b>(81) Designated States:</b> JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>In English translation (filed in Swedish).</i>
<b>(54) Title:</b> INCREASED DEPTH OF FIELD FOR PHOTOGRAPHY  <b>(57) Abstract</b> <p>The invention comprises a method and means for achieving increased depth of focus at photography. The method creates an improvement of depth of field at use of traditional "Tilt and Shift" - technique, and increased possibilities to obtain good depth of field with other and quite ordinary cameras. The method is primarily meant for electronic cameras, where the image is created electronically from a sensor in the camera and is based on a multi-photo technique. Several photos are shot with different focused parts of the scene subjects in respective photo, and a basic image is integrated by contributions from the different images. Calculated image transfers based on lens-/sensor settings for respective image, compose a starting point for corrections of images and selection of respective image contributions.</p>		

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Increased depth of field for photography.  
Method and means.

Field of the invention.

The invention comprises a method to increase the depth of focus (or field) for photography, and means for the method. The method constitutes an improvement of the depth of focus at use of traditional T / S - technology, "Tilt and Shift", and an increased possibility for improved depth of field with other and quite ordinary cameras. The method is mainly aimed for digital cameras, where the image is created from a sensor in the camera, instead of on a photographic film. By use of present scanning technology however, it is easy to transfer a film photo to an electronic image. The method can be used also for those cases. In the following the method is mainly presented for the cases, when the picture is created electronically directly in the camera.

In T / S cameras one or both of the lens and the "image plane" are movable. The image plane is that plane, where the film or the sensor is positioned. A plane in the scene is sharply focused in a "focused plane", which might be localized in front of, back of or cutting the image plane. Proportional to the distance between the image plane and the focused plane, the blurring grows larger in the image. In T / S cameras the photographer often views the image on a focussing screen positioned in the image plane. He controls the camera settings for a focused image on the focussing screen. Then he places the film / sensor in this position and shoots.

Photographers use many different ways of working. The profession is often creative, sometimes artistic. In practice the photographer puts the camera in position directed to the subject, arranges the image plane in the desired perspective, usually vertical, as we are used to view the world from a vertical perspective. Tilting an ordinary camera upwards, e g for placing a church tower inside the seeker, the camera will produce an image of the tower with a tilting perspective, showing a tower tilting or falling in. Parallel vertical lines are no more parallel in the image.

Then the photographer focuses and positions the subject for the image. Here difficulties might arise, which the invention can solve. The focal aperture is not only used for control of the light strength, but also for increasing the depth of field, e g at product photography. Increased exposure can compensate smaller apertures. However long time of exposure implies risks for mechanical disturbances blurring the sharpness.

T / S cameras are used for product photography, and when there is a desire to increase the depth of field from what an ordinary camera can offer. A close picture on a product with large extension in distance, might be given focus both on the front and back parts, by tilting the focal plane, cutting the front as well as the back part of the product image. The tilting might be arranged in two ways. One by positioning the film or sensor in the tilting image plane. The other by tilting the lens instead, turning the focal plane into the desired angle. Usually a vertical image plane is desired, obtaining a vertical perspective, and then there is just the method of tilting the lens, until the focal plane is positioned vertically in the desired image plane.

As subjects generally are not extended just in a plane of two dimensions, but are three dimensional bodies with varying extensions, also focal aperture reductions are used to decrease the angle of refraction from the lens. Thus the image plane can be farther from the

real focus, without too large blurring errors. However the subject or the light conditions might reduce the possibilities.

Invention functions.

The present invention concerns a method to achieve sharpness and depth of field for a still photo by use of multishots, where different camera settings can be used including aperture reduction technique. The method utilizes possibilities for digital image transfer after the shot, and the involved processes might be performed using automatic methods to various extents. An operator might also in interactions on computer screens, manually improve and control the result of the processes.

The method comprises:

1. The camera sensor is turned into a suitable focal plane and the photo is shot.

Then the perspective can be turned into a desired position by image transformation. One way to do this is sensing the sensor turning in relation to the desired perspective and feed data to a calculation unit, which calculates how much the image should be turned and makes the transformations. E.g. if the image is tilted an angle  $u$  related to the desired vertical plane, then the image plane can be turned around its front edge by  $u$ .

Then image points at the distance  $a$  from the axis would be scaled to the distance  $a \cdot \cos u$  from the axis. Those points are also moved closer to the lens, a distance  $a \cdot \sin u$ , which means the same reduction of scale as moving the image the corresponding distance closer to the lens, i.e. a distance  $b$  to the lens related to  $(a \cdot \sin u + b)$ . This is easily illustrated by drawing radiation lines through the optical center to respective image point. Thus turning the image around the axis, the points on the image will be projected through simple geometrical rules to the new image plane.

The choice of turning axis can be transferred as turning around another axis plus a transversal movement. Transversal movements of image elements, changing the distance from the lens, result in a proportional change of scale of the image element. Thus ordinary focusing gives rise to size changes. Knowledge about the relative image distance from the lens (the optical center) would be used for the size scale.

When there are defocused image parts, also the defocused area will be enlarged proportional to a general image enlargement. A defocused edge would be wider, if special actions are not performed. Such actions are included in the invention and will be presented further in the section about enlargement.

Projections of images might be performed as second steps, in turning to the right image perspective. The operator might fine tune or control the total process himself, by introducing the desired axis and turning. He can also define a certain speed of turn and study the image turning until it reaches the desired position, when he can stop the turning or interactively change the turn directions, fine tuning the right position.

The calculations can be performed using a basic image, which has been mapped to an increased number of image pixels. Then unnecessary losses of resolution can be avoided through the calculations and image processing.

The control setting of desired focus planes at photography, can be simplified and automatized, by the photographer setting the focus successively on those points, through which he wants the plane of focus. With known coordinates and focus settings the focus plane can be calculated and any turning of lens/sensor also. Simple calculation programs, including the camera optics can be stored in the pocket calculator, which can present the result as scale

partitions for a turning control. With a PC or other computers the operator can work with the image on the computer screen. Programs in the computer can control automatic focus measurements and calculation of focal plane and finally control turning and movements of the lens (sensor) to the right position. Thus the process can be performed as a production process, which is often wanted.

## 2. Creation of depth of field by use of several "stills".

At product photography the scene is often static, i.e. several photos can be shot reproducibly. A product with relatively large extension in distance, can be photographed from the same position with focus set for different parts for the different photos. On the different photos, different parts are respectively focused and defocused. They are also of different size.

### 2.1 Simple addition of image elements.

A sharp image of the product can be created by adding together focused different image elements from respective image. The process is made possible by first changing the image scale to the same size, according to 1 above. In many situations the operator might do the element selection on a computer screen and determine from which image respective element shall be transferred to the final image.

The process can also be automatic according to the invented methods. The focus for an image subarea is compared between images and respective focused image element is selected. The division borders between neighbouring image elements are chosen, e.g. where the defocussing is about the same from the different images. Any small deficiencies in the division interfaces might e.g. be handled by averaging that area between the respective images.

Simple product shapes such as a cereal box, might be photographed from a perspective, which gives a corner the shortest distance to the camera and other parts successively farther distant. A series of photos with successively changed focus can produce the said focused image elements for image element additions.

The cereal box photographed inclined from a high front position, shows three surfaces; a long, a short and an upper side. By tilting the sensor / lens a focused plane might be positioned along each of the three apparent surfaces. The three images are transformed by calculations to the selected basic image. If the sensor is turned, then the transformation also includes perspective returning.

After the calculations the product image can be combined from the three sharp image elements. In practice small deviations might have arisen in positions and sizes, between the three different photos. Disturbances might have shaken the positions and controls. So sharp borders and edges are identified for the different images and common corners and boundaries are matched together, through fine tuned corrections of position and scale for the different images.

The basic image might e.g. be an image with the right perspective e.g. a vertical sensor and a lens setting giving a focus plane for a product's front, or some other important part of the product. This basic "image" can be defined by sensor - lens settings and be the defined "basic image" without even being photographed, - also if a photo would have simplified the matching of the different photos to the basic image.

When additional pictures are desired for the integration of a sharp cereal box, then an extra focal plane might be positioned along the outmost left and right edges and through the diagonal of the upper surface, for helping adjustments of the said surfaces. When also the table surface is of interest, on which the box is standing, then a focal plane might be positioned also along this surface for an additional photo.

The integration of the final image might in this example be relatively simple, as each sharp element is easily identified and the defocused areas are substituted by sharp areas from other images.

Recalculations of perspective and scale of size is done to the defined basic image format, with the help of known settings for the sensor/lens. Analyses afterwards without knowledge of the settings, to find out the the image position relative to another image position, can be performed, but it might need some more processing.

Corrections at the integration of respective sharp image elements are performed using common image parts e g edges and corners. Often there are image and text details, which simplify the match. If the adjustments of an image wouldn't be good enough, e g dependent on a difficult perspective change, then local adjustments can be done for the different image elements. The sharp details are positioned in agreements with information from other images, and where distances in between is needed to be increased or decreased in a noncoherent way, the local area selected for that is preferable an area with slow light and colour variations.

## 2.2 Complex products.

Products might be more or less complicated in structure. There might be arms, poles, holes etc. Those can be identified by operators as special areas, "mountains and valleys", where a small area might contain large distance variations, and whereby several photos might be needed to cover the dynamics. Areas with mountains and valleys can also be identified automatically according to the invention. They are areas, which are characterized in causing strong defocussing in consecutive images, although the neighbouring image has sharp elements and though the transversal distance is close between the sharp parts of respective image. The operator can be alarmed about such and other problem areas by blinking on the screen, possibly at the position and with side comments. Often the operator might find focal planes, which can be positioned along steep mountains and with additional photos, better integrated sharpness can be obtained for such areas.

If the product has an arm or a pole, then one or more images might be shot with focal planes through the arm, such that this subject is shown as a sharp object. In a corresponding way as for the cereal box, those images are transformed to a basic image for integration with the other images on the product.

The process for image element identification might start at any photo, but it might be an advantage to start with the front or back. In this presentation the start is the front photo, and its center element.

An image area is selected. The area is surveilled considering borders i e border lines and edges with fast variations of light strength or colour. The colour resolution might be worse, however. The selection method might be the derivative, relative derivative ( $1/p * dp/dq$ ;  $q=x,y$ ), difference in light or colour strength, the relative difference of strength, etc. Those borders are compared with corresponding values for the photos below, and they are defined as belonging to the front photo, when the borders have not better focus in photo number 2. The space in between the borders includes surfaces and surfaces limited by borders belonging to photo 1 are also preliminarily assigned to this photo until further steps. A new adjoining image area is selected and the process is repeated, until the whole image has been worked through for the given series of photos, image 1 to n.

There are alternative search processes preferable in certain cases, e g when there are many image elements from different images in the selected search area. Then it might be better directly analysing edges of the present photos, and by comparisons identify the respective

belongings of the different edges. When the following areas been worked through, the final image can be integrated successively. Borders are selected and processed according to examples. When a border is an edge between two areas on different focused distances, the edge might be assigned to the first area, and the transition position between images might be selected at the edge on the second image.

### 3. Aspects on focus and sharpness.

#### 3.1 Sharpness when changing the scale of size, enlargements.

At enlargements all the image elements are enlarged. Those elements with significant distance extensions are enlarged including their defocused parts, which then might be more apparent. Defocused borders, e g the border between a red subject and a green background, are imaged giving a border width containing various red-green mixtures. For the same defocusing degree, the real edge position obtains 50% contributions from each side. A defocused point obtains a blurring defocused circle with smeared contributions from the point. Tips, corners and irregular shapes are imaged blurred, round smoothed and loosing their detail positions. Geometrical objects can be reshaped, by reconstruction of the edges to the corner tips etc. When the lack of sharpness is depending of the focusing distances, as in the described examples, the focused state is determined by simple optical rules, and according to the invention the focused image can be estimated and often also the defocused image borders can be corrected.

Digital photography is based on sensors, usually with smaller dimensions than the final photo image. The image processing includes enlargements and then an interest not loosing sharpness. Especially at product photography the subject consists of human designed structures, i e identifiable geometrical forms. Then there are preconditions to do corrections of defocused wellknown detail structures in many cases.

There is also a natural interest in good-looking product pictures, which emphasizes the importance of sharpness. Close up pictures on products enlarge the depth of focus problems, and then also the need of tool methods to improve the image quality.

Depth of field is relatively short at close ups. By reduction of the lens focal distance, the subject image decreases approximately proportional, but the relative depth of field might be increased. Subsequent magnifications increases the blurring too. Photography at distances, using zoom, might give the product a flat impression, which might be negatively experienced. With a small sensor and the product object filling the image, there is a need for a lens with a small focal distance, giving an angle of view, when looking at the photo, that gives associations to the right appearance of the product. Considering that aspect small products should be shot at short distances, and then also with short focal distances. The invention includes methods, based on knowledge about optical rules, for correction of defocussing, and it is based on knowledge about geometries for estimating structures and improving the sharpness.

#### 3.2 Correction of sharpness using optic methods.

Above, some methods have been presented, by which the image sharpness can be improved eg at product photography. Below there is a summary:

- a. Integration of several images on a product, being shot with different camera settings, including focus. Perspective turning and scale sizing can be used to match the different images to get a sharper image.

b. Adding information by use of photo with extra small focal aperture. By that the light will be extra reduced and the depth of field increased. Then object details with high light and contrast are imaged with larger depth of field. Such images can be used to match different images with less depth of field e g in the method in point (a) above.

c. Adding information from photos being shot with less focal distances. Rechanging the scale is simplified when the position is maintained of the subject relative the center of the lens. Depth of field might be improved also in those cases. On the other hand the image object grew smaller and is not utilizing the resolution at maximum. Also this type of photos can be used in the matching of images.

d. By tilting the lens/sensor, a corresponding tilting focal plane is positioned through the product. The image perspective is changed if the sensor is tilted, whereby a subsequent perspective turning is performed. This type of images can be used to give information about sharpness of elements which might be missing in point (a).

e. Consecutive photos can be used for optical calculations of the focus image distance of an image element and the real dimensions in this focused position. This method can be used e g for image elements that are out of focus on both neighbouring images.

f. By measuring the defocussing of edges and borders, the focused position of those image elements can be calculated and the border blurring be corrected.

g. Geometries can be inter- and extrapolated from consecutive photos and by that sharpness be estimated for defocused distances. The method might be simplified by storing a library of a number of usual geometries, and used in comparisons with the image information. Various methods, eg best correlation might be used.

### 3.3 Some optical relations regarding depth of field.

Usual optical notations and definitions:

a, b, f are distances to the lens from the subject, image, focus point.

H, h are the dimensions (e g the height) of the subject, its image.

$r_0, r_1$ , are the radius of the focal aperture, the radius of the defocused circle related to a sharp point.

A subject on the distance  $a + da$  is focused on the distance  $b - db$ .

Simple optical rules give:

$$1/a + 1/b = 1/f; \quad (1) \quad 1/b = (a-f) / a*f; \quad (2)$$

In the same way:

$$1 / b(1-db / b) = 1/f - 1 / (a + da); \quad (3)$$

(2) in (3) gives:

$$db / b = da*f / a^2 * 1 / (1 - f/a + da/a) \quad (4)$$



and

$$db/b \approx da*f / a^2 ; \quad (5)$$

Proportionality gives:

$$r_1 = r_0 * db/b ; \quad (6)$$

(5) in (6) gives:

$$r_1 \approx r_0 * da*f / a^2 ; \quad (7)$$

For the same subject distance (a) and depth of subject (da) it is obtained that the defocusing is decreasing, when the aperture ( $r_0$ ) and the focal distance (f) are decreasing. When f decreases, then the image also decreases, however. The relative unsharpness is:

$$r_1 / h \approx r_0 * da / (H*a) ; \quad (8)$$

$$r_1 / h \approx f * da / (H*a*2Q) ; \quad (9)$$

where the aperture  $Q = f/2r_0$  ;

Thus the reduction of the focal aperture is an important possibility for increase of the depth of field. The aperture cannot however be reduced too much, e g the light level arriving at the sensor must be large enough. The density of light for the image,  $I(h)$ , at the sensor is proportional to the density of light from the subject,  $I(H)$  according to:

$$I(h) \sim I(H) * H^2 * r_0^2 / (h*a)^2 ; \quad (10)$$

With (10) in (9) it is obtained:

$$r_1 / h \sim \{I(h) / I(H)\}^{0.5} * da*f / (H*a) ; \quad (11)$$

i e if  $I(h)$  cannot be further reduced and the light conditions and level are selected, then a reduction of the focal distance presents a possibility to improve the relative focusing.

### 3.4. Corrections at integration of the new basic image from the different image photos.

Photos, shot with the same relative position of the lens optical center relative of the scene subject, are simple to transform by perspective turnings and sizing, knowing the settings for the lens and sensor of respective photo. By a traditional camera, focal distance settings are the only focal plane setting available. That means that the photo series obtains parallel image planes, and no cutting focal planes for the same scene view. Together with the other applicable methods, described above, also those cameras can be used for advanced product photography, where depth of field and perspective otherwise are problems.

At multi-photo integration, small deficiencies might arise in practice. Tolerances in settings and mechanical disturbances and imperfections might cause changes between subsequent image shots. Photography with long exposure time might require extra stable basis for camera

and subjects, preventing disturbances from blurring the image. Until further actions, it is presently assumed that each useful image has good focus within its limited depth of field. Still corrections might be needed, after that the images principally have been transformed to the basic image format. Although each image mainly are in the right position, right perspective and right size. The following methods can be used for subsequent corrections:

- a. Consecutive images with different focus can be corrected, when a sharp element in one image corresponds to an unfocused one in neighbouring images. The position of the unfocused element can be determined, and by comparisons of detail positions in other images, positions, size of scale etc. can be coherently corrected. Common information for images is used. Calculation processes are faster, when a few well defined elements are selected for the comparison process and the elements preferably spread out over the image area. For the right image size the matching might be reduced to match the positions of the image elements. For errors in the scale size, the errors of scale might be obtained by "measurements" (calculations) of the distances between element positions. At perspective turning the scale of size might be different in different parts of the image e g different in the x- and y directions.
- b. Common sharp image elements are obtained from cutting focal planes e g for the example of the cereal box in point 2.1. By overlapping of common borders and edges the different images can be corrected and integrated.
- c. Added images can be shot, positioned at cutting focal planes e g to obtain sharp image elements in a tilted plane, which then can be recognized as sharp elements in different images. Then common references are obtained for and through several images.
- d. Images being shot with significantly reduced aperture obtain larger depth of field and can be references in corrections of other images, especially for elements with high light and contrast strength.
- e. Photos being shot with reduced focal distance can also give larger depth of field in spite of subsequent magnifications.

#### 4. Other examples of the method.

The sharpness of a product image can also be improved by increasing the resolution of the image in added photos, e g a product might be photographed with only parts of it filling the image (sensor) area. Then the sensor resolution is better utilized for this part of the total product image. The other parts of the product can be photographed with the same or different magnifications. Then the different images can be transformed to a basic image, where the whole desired image is included, and then with a high resolution. The resolution in the subsequent processing of the image is not limited by the condition that the whole image must be positioned on the sensor. The computer capacity can be used, creating a computer image with much higher resolution than the sensor. The method to integrate the different photos is easier, when as earlier, the position of the lens optical center is mainly maintained relative the image subject. E g that can be performed by photographing, turning the camera around the lens optical center. In the same way as earlier the integration is simplified when the different images are overlapped, where well defined elements are contained, and the overlap can also be used in comparisons between images for e g corrections. One or more images can also be shot with a lens with less focal distance, where essential parts of the whole image are contained, and contribute with general information about the basic image.

The method of selecting parts of the subject and photographing those with larger focal distances, possibly with the help of zoom, can be used together with the other methods, which are used for increased depth of field. The method might be applied for imaging very small details in a product, or for details used in the integration of image areas giving better resolution and by that a more accurate match.

#### 5. Examples on means for performing the improved depth of field.

In one preferred embodiment, the means consists of units in the camera and units in a computation equipment, e.g. a computer of PC type. The camera units consists of controls, which settings can be registered. The settings are for the lens and/or the sensor. For traditional cameras with electronic sensor, the distance focusing is made by the lens. T/S cameras might have controls for both the lens and the sensor, and those have generally large variability, i.e. they can also do tilting and give focussing and perspectives in many various planes. The settings can be controlled and read, and the lens and sensor might also, according to the invention, be related to the geometry of the camera design. The values on the optical system as focal distance, optical center or corresponding lens descriptions might be valuable in subsequent calculations after the photographing. It is simplifying when the position of the optical center is known, especially at lens changes between photos.

In the calculation unit, the computer, there are software which can store several images and work with transformations and transfer of images by size of scale, perspective turnings and positioning. If the optics and camera setting data are not included together with the image data transfer, the operator/photographer might himself read and feed in the values of the settings, or the computer makes the evaluation.

The choice of photo set up is made by the photographer, and he can set the camera manually or with help of the computer system. He can e.g. read the position for the point he will focus and read the connected focus setting. By reading three points a focus plane is defined, and a computer can help calculating the settings of lens/sensor to establish the desired focal plane. The computer can also contain additional program for automating all or various parts of the work. The control can also include selection of aperture from light measurements and other control of camera functions.

There are also included programs, which select image areas from respective transferred image, possibly with interactions from an operator.

Programs can be added that, possibly in interaction with an operator, select elements from different images, which are the basis for calculations of subsequent corrections of the images, including matching the basic image format for integration of focused image elements to the new focused basic image.

## Claims.

1. A method of photography with electronic image sensors, improving focus of images with such extensions that focus of a photo is not obtained over the whole image, but the depth of field is insufficient, then using information from several images or frames, where images are shot with different focus, characterized by; shooting the images mainly from the same relative position of the lens optical center in relation to the scene subject; and where images (a), being shot with different image distances are complemented with images (b), being shot with a method for increase of depth of field in relation to said image distances, according to at least one of the following methods, photos (b1) with effectively decreased aperture and photos (b2) with tilted focal planes relative to (a); and a method for successively integrating image information from different images, based on the following steps; where step (s1) comprises identification of a basic image format according to a chosen image or a defined image position, which is related to shot photos; and a step (s2) comprises transfer of the different images to the basic image format, by sizing of scale in relation to different focus, and where the perspective of an image is turned, this image is projected through geometrical calculations to the basic image format; and a step (s3), where a final basic image is built by the help of successively following the distance extension of objects, and with start from a focused image element at an image distance, the image area is successively increased (x,y-direction) while comparing images for neighbouring distances (z-direction) and when such a second image contains focused elements, the final image area is growing by integration, using element areas from the second image distance (z) and so on, and a selective order is to start at the front image and successively work backwards in subsequent images, and focus comparisons are preferably performed directly in the image domain, without any transformations of images to the space -frequency domain; and a step (s4) comprises identification of borders, which constitutes contours between objects belonging to different focused image distances, and which image distance differences are of the order of the depth of field or larger, and image element continuity according to (s3) is not contained, and defocused objects (o1) related to a first focused image distance, are spread over and disturbing the focused image on the second focused image distance, and the disturbance from (o1) is calculated from the sharp position to the defocused image distance and subtracted from the focused area of this image; and a step (s5) comprises utilizing one-dimensional image elements, as borders, edges and contours between objects, geometrical structures, colours etc., obtaining continuity at focus comparisons and image distance transfer in the step of (s3); and a step (s6) comprises utilizing images (b) to bridge over and to give continuity at image distance transfer, and (b1) especially for large depth of field of high light image elements, and by that also being used in (s4) to decrease the disturbances of high light defocused elements, and at use of (b2) the image integration can be simplified at photography of some objects; and a step (s7) comprises utilizing (s6) for fine tuning of step (s2), where (s6) supplies information about relative status of focused elements belonging to different image distances (a); and possibly in interaction with an operator, who might mark on the images, which parts from respective image he wants to have integrated in the final image, which simplifies the processes, then mainly comprising geometrical matching and fine tuning of the image elements to the right position and basic image format according to (s2).

2. A method according to claim 1, comprising; at least one tilted focal plane put through the subject image with tilting lens or sensor.

3. A method according to claim 1, comprising; at least one image in a focal plane, which is cutting other image planes and then offering elements in different images common sharp references.

4. A method according to one of the claims 1 - 3, comprising; determining the defocused width of borders, edges etc. and subsequently correcting the sharpness also for other image elements, selectively by also estimating the image positions of the sharp focused elements.
5. A method according to one of the claims 1 - 4, comprising; using consecutive images, calculating the image plane distance of an image element and its real focused extension at that plane, using that for image elements that are defocused in images at both side of the theoretically sharp image plane.
6. A method according to one of the claims 1 - 5, comprising; inter- or extrapolating geometrical structures, lines, rectangles, circles etc. from neighbouring image(s) to achieve focusing in defocused spaces in between, and selectively expanding the method to include storing of geometrical structures in a library for comparisons with obtained image elements e g by use of correlation, and when good agreements, the geometrical structures are used for corrections, the geometric structures possibly also including signs, letters or symbols.
7. A method according to one of the claims 1 - 6, comprising; correcting at least one of position, scale, perspective for different images, performing position comparisons between corresponding image elements in at least two images, and selectively using successive comparisons between different images, achieving several images related to each other.
8. A method according to one of the claims 1 - 7, utilizing the sensor resolution better, by photographing parts of a product with larger focal distance, the product part covering a larger part of the sensor area, comprising; photographing other parts of the product with the same or different magnification, where also image distances related to the focal distance might vary, and that different images are transferred to a basic image, where the whole image is covered and then with a corresponding higher resolution, where the capacity of the computer is utilized, which can give much higher resolution than that of the sensor, covering the whole final image, and selectively integrating different images, shot while keeping the position of the lens optical center relative to the subject, e g performing that, by turning the camera with the optical lens center as the turning point, and simplifying the image matching by overlapping images, where well defined elements are included and used at comparisons between images for possible corrections, and photographing one or more images with reduced focal distances, where essential parts of the total image are included in the same photo, and then might contribute with general overview information about the basic image.
9. Means for performing the tasks according to one of the claims 1 - 8, comprising control settings for the cameras, calculation unit for storing of image data with related settings and software programs for processing of several images and for calculations of transfer of images through change of scales of size, perspectives and positions, comprising; control settings for lens and sensor, relating respective position including angles to a geometry in the camera; and programs with algorithms, which use settings for respective image photo to transfer the images to a selected basic image, which also might be defined by settings, but that must not necessarily be a really photographed image; and a program unit, which possibly with the help of an operator, selects which image elements to be used from respective transformed image, and integrating those to a basic image.

10. Means according to claim 10, comprising; a program unit, possibly in interaction with an operator, selecting elements from different images, which are the basis for calculations of subsequent corrections of the images to the basic image format, achieving better integration of the different elements from the different images to the basic image.

11. Means according to any of the claims 9 - 10, aiding the photographer / operator with controls of the different photo focal plane settings, comprising; means for defining positions of points in the image, means for focusing those points and register the focus in the calculation unit, means in the calculation unit for calculating subsequent corresponding values for lens and / or sensor settings, means for control of the settings for photographing, and selectively adding means for storing basic data for respective control in the calculation unit, being e g a pocket calculator or a PC, for use at calculations and calibrations of values for control of the control means.

12. Means according to claims 9 - 11, comprising; means for the photographer to mark points on the computer screen image, and computer programs calculating and controlling the camera settings automatically by electronic controls.

13. A method and means according to any of the claims 1 - 12, where photography film are used instead of electronic sensors, comprising; photographing in the corresponding way, and subsequently scanning the film photos to obtain electronically stored images, which are subsequently processed in the corresponding way.

14. A method according to any of the claims 1 - 13, comprising; adding photo with reduced focal distance, selectively by zoom or change of lens, where image transformations are simplified by keeping the position of the lens optical centers relative the subject, giving a smaller image, not fully utilizing the sensor resolution, while depth of field has a potential to be increased, although by remagnification of the image also the defocused areas are magnified, the defocused elements obtaining improved focus and the image being used for adding information and to help matching other images.

1

INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SE 97/00017

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G06T 5/50  
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G06T, H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5282045 A (I.MIMURA ET AL), 25 January 1994 (25.01.94), column 5, line 30 - line 49; column 6, line 52 - line 60; column 8, line 5 - line 24, column 10, line 35 - line 47; column 12, line 56 - line 61	1,4-10,13-14
A	--	2,3,11,12
A	US 5148502 A (J.TSUJIUCHI ET AL), 15 Sept 1992 (15.09.92), column 2, line 14 - line 49	1-14
A	WO 9410653 A1 (MASSACHUSETTS INSTITUTE OF TECHNOLOGY), 11 May 1994 (11.05.94), page 34, line 16 - line 30; page 37, line 1 - line 18, figure 5	7-10,13
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

Date of mailing of the international search report

9 April 1997

22 -04- 1997

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**CORRECTED**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00017

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4661986 A (E.H.ADELSON), 28 April 1987 (28.04.87), column 3, line 20 - line 37  -- -----	1-14



**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

04/03/97

International application No.

PCT/SE 97/00017

Patent document cited in search report			Publication date	Patent family member(s)		Publication date
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				JP	1309478 A	13/12/89
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				US	4674125 A	16/06/87

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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> <b>G06T 5/50</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 97/25690</b> <b>(43) International Publication Date:</b> 17 July 1997 (17.07.97)
<b>(21) International Application Number:</b> PCT/SE97/00017 <b>(22) International Filing Date:</b> 9 January 1997 (09.01.97) <b>(30) Priority Data:</b> 9600083-1                      9 January 1996 (09.01.96)                      SE <b>(71)(72) Applicant and Inventor:</b> OLSSON, Kjell [SE/SE]; Såningsvägen 17, S-175 45 Jarfälla (SE).	<b>(81) Designated States:</b> JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>With amended claims.</i> <i>In English translation (filed in Swedish).</i>  <b>Date of publication of the amended claims:</b> 25 September 1997 (25.09.97)	
<b>(54) Title:</b> INCREASED DEPTH OF FIELD FOR PHOTOGRAPHY  <b>(57) Abstract</b>  The invention comprises a method and means for achieving increased depth of focus at photography. The method creates an improvement of depth of field at use of traditional "Tilt and Shift" - technique, and increased possibilities to obtain good depth of field with other and quite ordinary cameras. The method is primarily meant for electronic cameras, where the image is created electronically from a sensor in the camera and is based on a multi-photo technique. Several photos are shot with different focused parts of the scene subjects in respective photo, and a basic image is integrated by contributions from the different images. Calculated image transfers based on lens-/sensor settings for respective image, compose a starting point for corrections of images and selection of respective image contributions.		

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GA	Gabon			VN	Viet Nam

**AMENDED CLAIMS**

[received by the International Bureau on 15 May 1997 (15.05.97);  
original claims 1-14 replaced by amended claims 1-16 (5 pages)]

1. A method to increase the depth of focus, giving improved sharpness of subjects with such extensions that sharpness regularly cannot be obtained over the whole picture, using at least two images obtained with different camera settings, which selectively include change of focus, change of aperture, in mainly keeping the same position of the lens optical center relative to the subject, and combining information from those images to obtain one new image, including correction of contours, comprising:  
processing the result of still cameras by computer means, selectively external to the still camera functions, using data transferred from the camera on-line or through storage media, for principally non-synchronous or off-line processes in the steps of:
  - a. matching the different photo-images to the position, scale and perspective of a selected basic image in the steps of:
    - selecting a basic image;
    - identifying and localizing border lines and highly contrasting structures in a number of images;
    - calculating the geometrical transfer of a number of images to the basic image, selectively using position shifts, change of scale and perspective tilting;
    - choosing common references for valuating and/or correcting the matching of the images using the positions of identified common structures;
    - selectively adding at least one image of images, photographed with significantly reduced apertures, increasing the depth of focus and images photographed with tilted focus planes, cutting at least another image focus plane;
  - b. building a new created basic image from the matched images in the steps of:
    - using fast variations of light and/or colours as functions of area (x,y) based coordinates for determining the best focused images for an analyzed image element;
    - comparing for best focused states between images, using border lines and highly contrasting structures;
    - selecting for the new image, the identified border lines and structures from respective focused image;
    - selectively watching overlaps and loose ends of the structures;
    - selecting transition positions for structures with continuous extensions over neighbouring images, where the structures are divided belonging to different images;
    - selecting border lines for the steps of:
      - analysing a number of border line corridors, narrow pixel areas around borders, for differences on each side of the border line between respective images for the steps of;
      - separating between borders in the same focused image and borders between different focused images;
      - correcting the border line corridor, being a transition border between different images, reducing the spill over from the defocused corridor side to the focused corridor side;
      - defining transition positions at border lines, where the border line is the border between different focused images;
      - analysing the areas between border lines for indications of image elements with better focus from other images for the step of;
      - defining transition positions between structures belonging to different neighbouring images;

selectively correcting border line corridors and other transition positions between images by using information from added images, photographed with significantly reduced apertures or with tilted focus planes;  
selecting additional transition positions for the same images through areas containing slow variations of light and colour and containing no defined structures from other images;  
building the new created basic image through the transition positions between different images keeping continuity of light level;

**Claim 2.** A method according to claim 1, further comprising:  
analysing the speed of variation in light or colour, selectively using derivatives of, relative derivatives of, differences of, and combinations or quotients thereof and of the strenght of light or colours.

**Claim 3.** A method according to claim 1, further comprising:  
using the methods of reduced aperture or tilted image planes for correction of defocused spill over across borders between different focused images in the step of;  
selecting borders, where those methods give a focused image on both sides of the border;  
selecting this both-side focused image for the border presentation, or one-side focused images of the border corridor, after calculating and reducing the spill over to respective one-side focused image.

**Claim 4.** A method according to claim 1, further comprising:  
building the new basic image successively in the steps of;  
starting at a selected focused image element of a selected image;  
increasing the examined area continously, while comparing with neighbouring images;  
making transition of images, when element grows sharper at another image;  
increasing the new basic image area with the area from the present image;  
selectively starting on the front image and successively working towards the background.

**Claim 5.** A method according to claim 1, further comprising:  
building the new basic image, selecting strategies in the steps of;  
counting density of image border lines;  
selecting low density strategies for large low density areas;  
selecting high density strategies for small high density areas;  
building low density strategies on the steps of;  
connecting selected border lines of the selected image with affiliated border lines by defining transition positions across areas in between;  
transferring the closed image areas to the new basic image;

**Claim 6.** A method according to claim 1, further comprising:  
including to the computer means a man machine interface, MMI, for interactions with an operator;

reducing the complexity of the image processing by an operator selectively performing steps of;  
defining on the computer screen, which parts from which image to be transferred to the new basic image, reducing the processing to mainly image matching and final corrections of the parts in position and border defocusing;  
selecting details from different images for the image matching;  
selectively defining strategies for different areas for the new image building;

- 7 4. A method according to one of the claims 1 - 3, comprising: determining the defocused width of borders, edges etc. and subsequently correcting the sharpness also for other image elements, selectively by also estimating the image positions of the sharp focused elements.
- 8 5. A method according to one of the claims 1 - 4, comprising: using consecutive images, calculating the image plane distance of an image element and its real focused extension at that plane, using that for image elements that are defocused in images at both side of the theoretically sharp image plane.
- 9 6. A method according to one of the claims 1 - 5, comprising: inter- or extrapolating geometrical structures, lines, rectangles, circles etc. from neighbouring image(s) to achieve focusing in defocused spaces in between, and selectively expanding the method to include storing of geometrical structures in a library for comparisons with obtained image elements e g by use of correlation, and when good agreements, the geometrical structures are used for corrections, the geometric structures possibly also including signs, letters or symbols.
- 10 7. A method according to one of the claims 1 - 6, comprising: correcting at least one of position, scale, perspective for different images, performing position comparisons between corresponding image elements in at least two images, and selectively using successive comparisons between different images, achieving several images related to each other.
- 11 8. A method according to one of the claims 1 - 7, utilizing the sensor resolution better, by photographing parts of a product with larger focal distance, the product part covering a larger part of the sensor area, comprising: photographing other parts of the product with the same or different magnification, where also image distances related to the focal distance might vary, and that different images are transferred to a basic image, where the whole image is covered and then with a corresponding higher resolution, where the capacity of the computer is utilized, which can give much higher resolution than that of the sensor, covering the whole final image, and selectively integrating different images, shot while keeping the position of the lens optical center relative to the subject, e g performing that, by turning the camera with the optical lens center as the turning point, and simplifying the image matching by overlapping images, where well defined elements are included and used at comparisons between images for possible corrections, and photographing one or more images with reduced focal distances, where essential parts of the total image are included in the same photo, and then might contribute with general overview information about the basic image.
- 12 9. Means for performing the tasks according to one of the claims 1 - 8, comprising control settings for the cameras, calculation unit for storing of image data with related settings and software programs for processing of several images and for calculations of transfer of images through change of scales of size, perspectives and positions, comprising: control settings for lens and sensor, relating respective position including angles to a geometry in the camera; and programs with algorithms, which use settings for respective image photo to transfer the images to a selected basic image, which also might be defined by settings, but that must not necessarily be a really photographed image; and a program unit, which possibly with the help of an operator, selects which image elements to be used from respective transformed image, and integrating those to a basic image.



- 13 11. Means according to any of the claims 9 - 10, aiding the photographer / operator with controls of the different photo focal plane settings, comprising; means for defining positions of points in the image, means for focusing those points and register the focus in the calculation unit, means in the calculation unit for calculating subsequent corresponding values for lens and / or sensor settings, means for control of the settings for photographing, and selectively adding means for storing basic data for respective control in the calculation unit, being e g a pocket calculator or a PC, for use at calculations and calibrations of values for control of the control means.
- 14 12. Means according to claims 9 - 11, comprising: means for the photographer to mark points on the computer screen image, and computer programs calculating and controlling the camera settings automatically by electronic controls.
- 15 13. A method and means according to any of the claims 1 - 12, where photography film are used instead of electronic sensors, comprising; photographing in the corresponding way, and subsequently scanning the film photos to obtain electronically stored images, which are subsequently processed in the corresponding way.
- 16 14. A method according to any of the claims 1 - 13, comprising; adding photo with reduced focal distance, selectively by zoom or change of lens, where image transformations are simplified by keeping the position of the lens optical centers relative the subject, giving a smaller image, not fully utilizing the sensor resolution, while depth of field has a potential to be increased, although by remagnification of the image also the defocused areas are magnified, the defocused elements obtaining improved focus and the image being used for adding information and to help matching other images.

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